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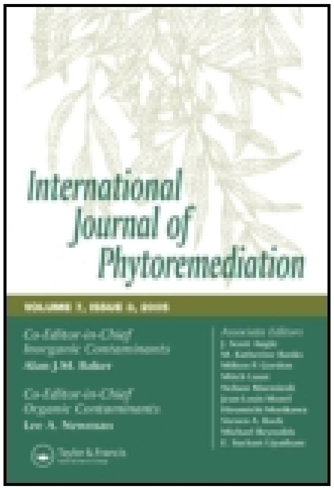

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The Potential of *Canna lily* for Wastewater Treatment Under Indian Conditions

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Low cost treatment of polluted wastewater has become a serious challenge in most of the urban areas of developing countries. The present study was undertaken to investigate the potential of *Canna lily* towards removal of carbon, nitrogen, and phosphorus from wastewater under sub-tropical conditions. A constructed wetland (CW) cell supporting vegetative layer of *Canna lily* was used to treat wastewater having high strength of CNP. Removal of biological oxygen demand (BOD_3) and chemical oxygen demand (COD) varied between 69.8–96.4% and 63.6–99.1%, respectively. C. lily could efficiently remove carbon from a difficult to degrade wastewater at COD:BOD ratio of 24.4. Simultaneous reduction in TKN and nitrate pointed to good nitrification rates, and efficient plant assimilation as the dominant nutrient removal mechanism in the present study. Suitable Indian agro-climatic conditions favored plant growth and no evident stress over the Canna plant was observed. High removal rate of 809.8 mg/m^2-day for TKN, 15.0 mg/m^2-day for nitrate, and 164.2 mg/m^2-day for phosphate suggests for a possible use of Canna-based CW for wastewater treatment for small, rural, and remote Indian communities.

keywords: *Canna lily*, constructed wetland, CNP

Introduction

Conventional treatment of wastewater is an energy-intensive expensive process which results in production of secondary toxic sludge and requires regular monitoring of skilled personnel. The task is even tougher in developing countries where large volume of wastewater is generated with a diverse nature of pollutants present in it. Removal of nutrients like carbon, nitrogen, and phosphorus (CNP) during tertiary treatment is therefore a challenging task in developing countries since it involves extra input of chemicals and energy (Kivaisi 2001). The demand for energy and water quality is rising in densely populated developing countries, so it becomes imperative to investigate and devise the low cost and sustainable treatment technologies for wastewater treatment.

Cost-effective treatment of polluted water has become a serious challenge in most of the cities of the world. Urban sprawl has resulted in increased impervious surfaces like roads, rooftops, parking spaces etc. leading to higher surface runoff and mobilization of pollutants (Davis *et al.* 2009). Urban runoff is designated as a leading impairment source for water bodies and third largest pollution source for lakes (USEPA 1997), and the effects on receiving waters are quite diverse and complex (Hoffman *et al.* 2002). Constructed wetlands (CWs) are reported to be inexpensive and promising tool for nutrient removal (Vymazal 2007) and stabilization of secondarily treated wastewater with very low energy input rates (Bergdolt *et al.* 2013). CWs have also been claimed to reduce BOD_5 and *E. coli* for unrestricted urban use and recreational swimming in temperate climate, respectively (Jokerst *et al.* 2011). There is significant decrease in BOD_5 during conventional secondary treatment of wastewater, but the removal of nitrogen and phosphate remains limited. Therefore, most of the studies highlight the use of CWs for nutrient removal during the treatment of secondarily treated sewage and stormwater. Presence of excess nutrients, otherwise, may trigger eutrophication in wetlands or other water bodies leading to chocking and other harmful environmental effects. Among the best management practices (BMPs) for storm-water management, bioretention system consisting of the surface layer of mulch supporting a layer of vegetation over it, reduces runoff, prevents soil erosion, and improve water quality in a natural aesthetically pleasing manner (Hseih and Davis 2005). Therefore bioretention systems and constructed wetlands are substantially similar with slight differences of media composition, and regulation of flows in and from the system. An important difference is the infiltration of water in the deep soil in bioretention/biofiltration systems.

The role of macrophytes (Yilmaz and Akbulut 2011) and emergents in water treatment and removal of pollutants (Mina *et al.* 2011; Vymazal 2013) has been documented in several studies, but the studies on *Canna* spp. are limited. An important aspect associated with *Canna* plant is its higher growth rate with significantly high biomass production (Chen *et al.* 2009) which is directly related to nutrient uptake, and

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tolerance to water stress and chemical fluctuations, making it a suitable candidate for phytoremediation. Another study by Abou-Elela *et al.* (2013) also reported a very high dry biomass accumulation by *Canna lily* compared to *Phragmites australis*, an extensively studied potential plant for wastewater treatment in CWs. Apart from it, the aesthetically pleasing look, and floriculture possibility adds a new dimension to its use in constructed wetlands.

A study by Belmont and Metcalfe (2003) reported that *Canna*, has limited growth and cannot survive in cold winter in northern hemisphere (under temperate conditions) and therefore has a limited use in CWs in such countries. On the other hand, its use in tropical and subtropical countries is expected to yield better results and it can complement the deficient removal rates of conventional treatment systems. The effect of wastewater on growth parameters of *Canna* should also be investigated to ascertain the stress of diverse pollutants, if any, over the plant. Therefore, the present study was initiated to investigate the potential of *Canna lily* in nutrient (CNP) removal from domestic wastewater/sewage under subtropical conditions.

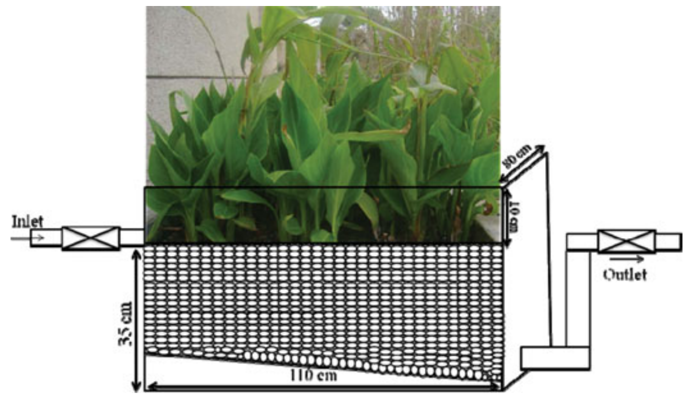

Fig. 1. Configuration of wetland cell used during the study.

Materials and Methods

Wetland Configuration

A bench scale CW cell (1.1 m length × 0.8 m breadth × 0.35 m depth) located in the campus of Delhi Technological University (DTU) was used during the study. The CW cell was located outdoors in a semi-arid climate with no protection from temperature, sunlight, rainfall, and evapotranspiration to study the removal under natural conditions. The inlet and outlet nozzles were provided to feed raw water and collect the outflow, respectively (Fig. 1). The cell was packed with sand-gravel bed to a depth of 0.35 m and a space of 10 cm over it. The size characterization of sand-gravel packing medium (Fig. 2) represented the graded soil profile with voids in between to facilitate easy root penetration throughout the treatment CW cell. A slope of 1.0 cm was provided along the length to facilitate flow. Fifty (50) plants of *Canna* with mean shoot length of 33.8 ± 4.7 cm were grown in the wetland cell in the month of March (representing late spring), and an initial period of 15 days was provided to let the plant stabilize in CW cell before undertaking the removal studies. No senescence or death of plants was observed during the initial period of stabilization.

Wastewater Analysis

The wastewater was collected from a collection pond located at 28.7° N latitude and 77.1° E longitude in DTU campus, which receives wastewater from nearby residential blocks and partially from a University hostel. Physicochemical characterization was done as per the standard methods (APHA 1998) to determine the average values (n = 5) of pH, Total dissolved solids (TDS), Biological Oxygen Demand (BOD_3), Chemical Oxygen Demand (COD), Available phosphate/orthophosphate (AP), Total Kjeldahl's Nitrogen (TKN), and nitrate. Based on the values determined, synthetic wastewater was prepared in the laboratory using glucose, Potassium dihydrogen orthophosphate (KH_2PO_4), Ammonium Sulphate [$(NH_4)_2SO_4$], and potassium nitrate (KNO_3) dissolved in groundwater from DTU pump-house (pH 7.5; Na^+ 100 mg/l; K^+ 4.0 mg/l; Ca^{2+} 40 mg/l; Mg^{2+} 19.5 mg/l; $CO_3{}^{2-}$ 21.6 mg/l; $HCO_3{}^-$ 310 mg/l; Cl^- 54 mg/l; and $SO_4{}^{3-}$ 60 mg/l) to simulate the naturally prevailing characteristics of wastewater.

Experiments, Data Collection & Statistical Analysis

After an initial period of 15 days for stabilization of *Canna lily* plants in wetland cell, synthetic effluent having a pH of 7.5, TDS - 2200 mg/l, BOD_3 – 45 mg/l, COD – 1100 mg/l, nitrate – 1 mg/l, TKN – 50 mg/l, and available phosphate – 15 mg/l was fed to the system with a total volume of 150 liters initially. Later, 15 liters of synthetic wastewater was fed to the system on regular intervals of 24 hours to make up for the nutrients; and evapotranspiration losses. The sample of treated wastewater was regularly collected from the outlet and analyzed for a period of 30 days. The analysis of the treated wastewater was done as per the standard methods; in triplicates using AR-grade chemicals and reagents. Based on the results obtained,

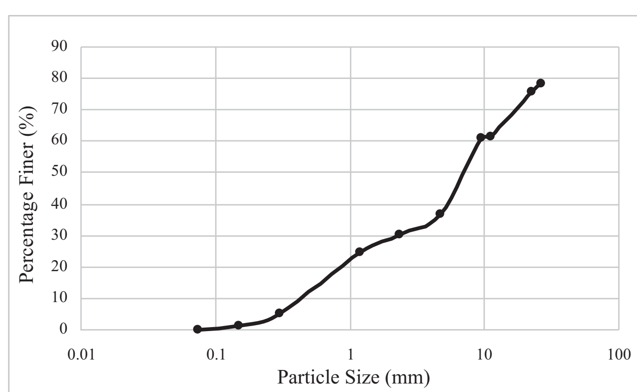

Fig. 2. Particle size distribution of sand-gravel packing medium used in CW cell.

Table 1. Average meteorological conditions during the study period.

Minimum Temperature (°C)	24.2 ± 2.5
Maximum Temperature (°C)	39.2 ± 3.2
Relative Humidity (%)	37.0 ± 9.2
Wind Speed (m/s)	1.82 ± 0.51
Solar flux (W/m^2)	224.5 ± 4.0
Sunshine hours (hrs)	9–11

nutrient removal efficiency (percentage basis), and removal rate (mg/m^2-day) of the CW cell were computed. The statistical analysis of data was done on MS-Excel and Minitab 15 software.

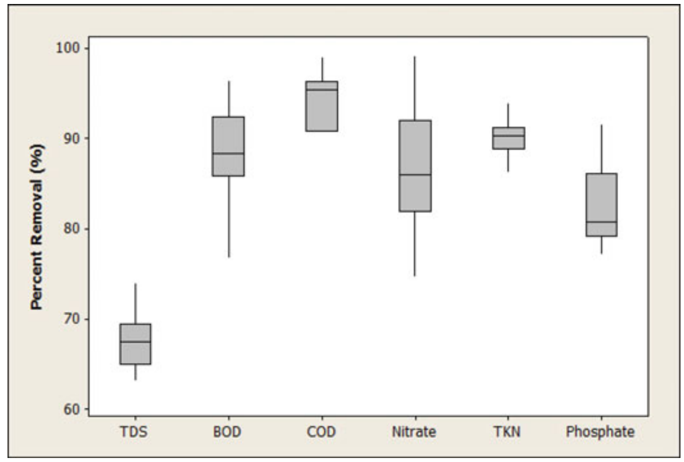

Fig. 3. Percentage removal of CNP by *Canna lily* in constructed wetland.

Results and Discussion

The growth of *Canna lily* depends on the nutrient availability and agro-climatic conditions. Therefore, the meteorology was monitored regularly throughout the study period (Table 1). The values obtained are classified in semi-arid to arid condition with sufficient availability of sunlight favoring the plant growth, which in turn regulated substantially high uptake/removal of nutrients from wastewater. The values of different parameters monitored in the inlet and outlet of CW cell are given in Table 2.

Removal of Dissolved Solids

The nutrient removal from wastewater depends on the water demand/uptake of the plant. *Canna lily* has a water demand of the order of 1.4 liters/plant/day (Chen *et al.* 2009) as studied in subtropical to semi-arid climates of Louisiana and California. This demand is 3–5 times more than the other wetland vegetation. Apart from it, meteorological conditions play an important role in regulating evapotranspiration. The semi arid conditions result in higher transpiration and as a result higher uptake of water. Since the average maximum temperature was of the order of 39.2°C, the water uptake was observed to be higher, and so was the removal of dissolved available nutrients. The total dissolved solids (TDS) content in inlet water was 2200mg/l, as compared to the average level of 708.9 mg/l in outlet. Percentage removal of TDS varied from 63.2 to 74.1 with an average value of 67.8% (Fig. 3). The average removal rate for TDS was 31.9 gm/m^2-day.

Removal of Organic Carbon

Organic carbon in wastewater was monitored in terms of BOD_3 and COD. The BOD_3 in outflow varied from 2 to 13 mg/l with a mean value of 6 mg/l, as against the value of 45 mg/l in inlet. The percent removal ranged from 69.8 to 96.4 with an average value of 87.3% (Fig. 3). The removal rate of BOD_3 was 721.5 mg/m^2-day at a loading rate of 767 mg/m^2-day with a hydraulic retention time (HRT) of 24 hours. The concentration of COD in influent was 1100 mg/l representing it to be high strength wastewater (Metcalf and Eddy Inc. 1991). Percent removal of COD ranged from 63.6–99.1% (Fig. 3) with an average value of 92.8%. The removal rate was 18.1 gm/m^2-day at loading rate of 18.8 gm-COD/m^2-day for a HRT of 24 hours. Average effluent COD concentration was 140 mg/l but it stabilized at around 40 mg/l towards later half of the study period. Gearheart (1998) too reported the effluent COD concentration of 40 mg/l when the COD loading rate was 14 gmCOD/m^2-day for a wetland treating domestic wastewater. Ayaz and Acka (2001) have reported the same effluent concentration at a loading rate of 40 gmCOD/m^2-day; whereas Reed *et al.* (1988) had recommended 60 gmCOD/m^2-day for optimum COD removal in a natural system. The present study reports significantly high removal efficiency of *Canna lily* for BOD_3 and COD from a difficult to degrade synthetic effluent with COD:BOD ratio of 24.4, as against the lower removal efficiency of *Typha latifolia* and *Ipomes spp.* based surface flow wetland system treating industrial effluent with COD:BOD ratio of 17 (Panswad and Chavalparit 1997).

Removal of Nitrogen

Total nitrogen in wastewater was measured as the sum of Total Kjeldahl's Nitrogen (TKN) and nitrate. Concentration of nitrite was not determined since it remains very low and insignificant compared to that of ammonium and nitrate in treatment wetlands (Kadlec and Knight 1996; Belmont *et al.* 2004). The initial (influent) concentration of TKN was 50 mg/l classifying it as strong wastewater (Metcalf and Eddy 1991); and the effluent concentration ranged between 2.9 to 15.4 mg/l with an average value of 5.3 mg/l. The removal rate was observed to 809.8 mg/m^2-day at a loading rate of 852.3 mg TKN/m^2-day for a HRT of 24 hours. The percentage removal varied from 69% to 94% with an average value of 89% (Fig. 3). Percentage removal of similar order has been reported by Ayaz and Acka (2001) to study removal of ammonia by *Canna*. They observed that removal of ammonical nitrogen was around 88% and accounted it for plant assimilation and nitrification. Davis *et al.*

Table 2. Values of different parameters during wastewater treatment by *Canna lily*.

ParameterDay	pH	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	Nitrate (mg/l)	TKN (mg/l)	Phosphate (mg/l)
Inlet	**7.5**	**2200**	**45**	**1100**	**1.00**	**50**	**15.00**
Outlet10-Apr-12	6.8	680	6	1570	0.32	15.4	1.76
11-Apr-12	6.9	710	5	100	0.07	6.8	3.06
12-Apr-12	6.9	730	5	100	0.07	6.3	3.21
13-Apr-12	6.9	750	3	400	0.10	5.4	3.16
16-Apr-12	7.0	690	6	200	0.15	5.3	2.79
17-Apr-12	6.9	660	6	100	0.17	5.6	2.80
18-Apr-12	6.9	770	5	100	0.21	4.4	2.77
19-Apr-12	7.0	800	5	100	0.11	4.6	2.72
20-Apr-12	6.8	675	6	70	0.24	4.4	3.20
23-Apr-12	7.0	690	4	40	0.20	4.5	3.20
24-Apr-12	6.9	720	3	50	0.17	5.5	2.94
25-Apr-12	6.9	668	3	50	0.16	4.3	2.72
26-Apr-12	6.9	730	6	50	0.11	4.8	2.85
27-Apr-12	7.0	780	4	60	0.10	2.9	2.87
30-Apr-12	7.0	810	4	10	0.16	4.8	2.14
01-May-12	6.9	720	5	30	0.07	4.1	2.17
02-May-12	6.8	610	3	40	0.03	4.8	2.29
03-May-12	7.1	780	10	60	0.19	3.7	1.90
04-May-12	6.8	620	13	30	0.08	5.2	1.96
07-May-12	6.9	770	10	40	0.09	3.3	1.95
08-May-12	6.8	570	13	30	0.16	4.1	1.69
09-May-12	6.8	780	6	30	0.01	6.7	1.18
10-May-12	7.0	620	3	40	0.06	5.9	1.52
11-May-12	7.1	680	2	50	0.03	4.5	1.95
Range	**6.8–7.1**	**570–810**	**2–13**	**10–1570**	**0.01–0.32**	**2.9–15.4**	**1.52–3.21**
Mean± SD	**6.9± 0.08**	**708.9± 64.76**	**5.7± 2.99**	**139.58± 314.82**	**0.1± 0.07**	**5.3± 2.36**	**2.5± 0.60**

(2001) have also suggested 60–80 % removal of TKN by a bioretention media supporting a vegetative layer. Nyakang'o and van Bruggen (1999) reported 87–90% removal of total nitrogen in a constructed wetland to treat domestic wastewater in Nairobi, Kenya. TKN removal in the present study was efficient, and it matches with other studies suggesting a possible use of *Canna*-based CW for wastewater treatment in developing countries. Nitrate concentration in influent was 1 mg/l to supplement plant growth in case nitrification in the experimental system remains limited. Nitrate was reduced to 0.01 to 0.32 mg/l concentration in the effluent with an average value of 0.1 mg/l. Good removal efficiency for TKN suggests significant nitrification rate facilitating conversion of ammonium ions to nitrate, and subsequent removal of nitrogen. The observed removal rate of nitrate was 15.0 mg/m^2-day at a loading rate of 16.0 mg/m^2-day. Average percentage removal of 86% (Fig. 3) with respect to initial concentration was observed during the study. Generally, reduction in concentration of TKN is observed slightly higher than that of nitrate since plant assimilation as well as nitrification of ammonium to nitrate account for TKN removal, whereas removal of nitrate takes place by plant assimilation alone (Chen *et al.* 2009). Simultaneous reduction in TKN and nitrate points to efficient plant uptake and good nitrification rate in the present study. Since assimilation by plants is efficient, other removal mechanisms do not play a significant role in planted constructed wetland (Zhang *et al.* 2007 ; Chen *et al.* 2009). The percentage removal of nitrogen as observed in our study is higher or almost of the order as observed in other studies. Belmont *et al.* (2004) had observed 76.7% nitrate removal in cattail based sub-surface flow wetland treating domestic wastewater; and DeBusk *et al.* (1995) too observed about 85% removal of TKN in *floralta limpograss* and *alemangrass* microcosms. They also concluded that *Canna lily* had a significantly high removal rate of nutrients compared to some other emergent macrophytes. Ammonical nitrogen removal of the order of 97–99% has also been observed by Brix *et al.* (2003) and Laber *et al.* (2003) in Denmark and Nepal, respectively, which highlights the use of wetlands in wastewater treatment in different regions of the world.

Removal of Phosphate

Phosphate in wastewater was measured as available phosphate (orthophospahte). The initial concentration of orthophosphate was 15.0 mg/l considered as high strength wastewater. The phosphate concentration in outflow varied between 1.52–3.21 mg/l with an average value of 2.5 mg/l. The percentage removal varied from 77.3 to 91.6% with an average of 82.6% (Fig. 3). The removal rate was observed to be 164.2 mgP/m^2-day at an initial loading of 178.6 mgP/m^2-day after the HRT of 24 hours. DeBusk *et al.* (1995) have also reported similar removal rate of 173 mgP/m^2-day by *Canna lily* based CW treating dairy wastewater. The major removal mechanisms of phosphate might be uptake by plants and adsorption by antecedent substrate (soil and sediments) (Kadlec and Knight 1996). Most of the studies have reported phosphate removal ranging between 50–80% with respect to initial concentration. Brix *et al.* (2006, 2011) have reported 46% removal of phosphate from sewage using *Canna* with other two species. Another study by Kimani *et al.* (2012) reported 53 % removal of total phosphate from wastewater from a flower farm. The high removal efficiency of 82.6% might be due to the preferred removal of orthophosphate by plants as observed in the present study. Higher removal rates of available phosphate may also be attributed to higher uptake by *Canna* plants during the initial growth phase before maximum growth is attained as reported in other studies too (Boyd 1969; Vymazal 1995). The phosphate removal rate of plants may decrease after attaining maturity and with increasing biomass (DeBusk *et al.* 1995) as observed in bioretention systems. Another reason for higher removal rate could be difference of agro-climatic region favoring higher growth rates of wetland vegetation (Vymazal 2005) under Indian conditions. Similarly high phosphate removal efficiency of 88% was reported by Nyakang'o and van Bruggen (1999) in Nairobi, Kenya attributing to the role of agro-climatic regions. The redox conditions present in wetland might also affect the rate of phosphate removal since aerobic conditions are more favorable for P sorption and coprecipitation by ligand exchange reactions with hydrous oxides of iron and aluminum (Bostrom *et al.* 1982).

Effect of Wastewater on Canna lily

Since the nutrients (CNP) are taken up by the plant for its growth and metabolism, it becomes imperative to monitor the growth of the plant and to study its biochemical constituents. The plant growth was monitored in terms of root length, shoot length, and plant density; and the biochemistry of *Canna lily* was studied by determining its Chlorophyll a, chlorophyll b, and carotenoids (Table 3). The growth parameters of the plant revealed 1.2 times increase in plant density, 2.4 times increase in shoot length and 2.8 times increase in root length. A significant increase in the biomass of the plant may be correlated to the utilization/ assimilation of nutrients from the waste water with no adverse physical effect on the growth. The biochemical constituents had an insignificant small change in terms of chlorophyll and carotenoid concentration. Slight decrease in the concentration of chlorophyll a and an increase in chlorophyll b may be attributed to the temperature/ heat stress exerted over the experimental plants in the last phase of the study as reported in other studies too (Shi *et al.* 2004). The daily maximum ambient temperature raised from 30°C (in initial phase) to 43°C (in final phase) during the study which results in enhanced evapo-transpiration and an elevated stress over the plant. No direct stress of wastewater over the growth of *Canna lily* could be established.

Table 3. Physical and biochemical Charecteristics of *Canna lily* during the study.

Parameter	Initial	Final
Chlorophyll 'a' (mg/l)	10.71	9.44
Chlorophyll 'b' (mg/l)	2.44	3.87
Total chlorophyll (mg/l)	13.12	13.27
Carotenoids (mg/l)	0.06	0.07
Average Root length (cm)	21.0	57.7
Average Shoot length (cm)	33.8	80
Density (plants/m^2)	50	59

Conclusion

Removal of nutrients (CNP) from wastewater by *Canna lily*-based CW is found to be potentially effective in the present study. Significantly high removal efficiency of *C. lily* stresses upon the use of such plants in high-strength-wastewater treatment particularly under tropical conditions. Average removal of BOD_3 (87.3%) and COD (92.8%) from wastewater with COD:BOD ratio of 24.4 signifies the use of C. lily for treating selected industrial effluents with high COD:BOD ratio. Simultaneously high removal of TKN and nitrate suggests of good nitrification rates in plant rhizosphere to facilitate conversion of ammonium ions to nitrate and subsequent uptake by the plant. High removal efficiency for TKN, nitrate, and phosphate reflects efficient uptake by plants, which in turn points to plant assimilation as the dominant removal mechanism in the present study. Apart from it, the plant represented no direct physical or bio-chemical stress reflecting of its use in other areas too. Climatic conditions favoring plant growth under Indian conditions make *Canna lily* a suitable wetland plant for nutrient removal particularly for small and remote communities. The study concludes that *C. lily* based CW can be a viable alternative for wastewater treatment especially when nutrients (CNP) are the treatment target.

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